

## RECENT TRENDS AND ADVANCEMENTS IN THE FIELD OF MICRO ELECTRICAL AND MECHANICAL SYSTEMS (MEMS) TECHNOLOGY

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### ABSTRACT

*The use of Micro Electrical and Mechanical Systems (MEMS) in the field of electrical and mechanical based domains is becoming the brains of micro devices day by day. This paper represents about the recent trends that MEMS concept has been profoundly used. MEMS sensors technology has been used in the various domains such as engineering, medical & space equipment, telecommunication RF systems, bio technology etc., By this paper we have shown some of the technologies already existed in each domain which will give the immense cutting edge enhancements, improvements in research and shows the need of MEMS concept in the field of research. The development of MEMS technology will be integrating the mechanical and electrical systems into the single base which will be the building blocks for the overall equipment.*

**KEYWORDS** MEMS, Sensors, Lithography, Accelerometers, Cerebrospinal fluids, Space Thrusters & Diagnosis

**Received:** Nov 03, 2017; **Accepted:** Nov 23, 2017; **Published:** Dec 01, 2017; **Paper Id.:** IJMPERDDEC201755

### INTRODUCTION

MEMS are the technology of microscopic devices like NEMS and transistors used in mechanical electrical integrated equipment's. In recent years, micro-electromechanical systems (MEMS) based sensors have shown huge attraction in machinery due to their low power consumption, low cost, small size, mobility, and flexibility. It merges at nano scale into nano electro mechanical systems but not as same as NEMS<sup>[1]</sup>.

### MEMS ARE CLASSIFIED ON THE BASIS OF

- Micro sensors
- Micro structures
- Micro electronics
- Micro actuators

MEMS are referred as micro machines in Japan and MST (micro system technology) in Europe. MEMS fabrication done by semiconductor device fabrication, and deposition of layers of material by patterning of photo lithography(e.g.: used in the jet printers to scan and print the file).

In past decades MEMS become a common products of integral part in many systems, from the regular academic experience MEMS technology experimentally implemented worldwide and taken a while to happen.

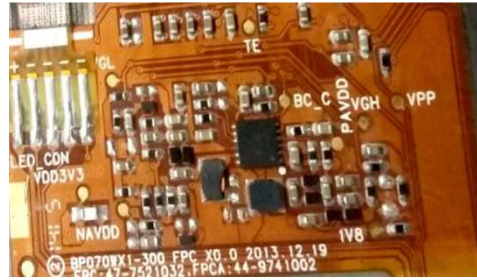
MEMS sensors give the outstanding parameter outputs for every domain. For high performance solution and most cost effective history teaches about the integration. Sensor and signal conditioning are one of the chip, part of an Analog device and pursued an integration approach to MEMS. The body of the sensor can move in the X and Y

axes, the MEMS structure above the substrate such that poly silicon springs where suspend. 32 sets of radial fingers around the four sides of the square proof mass, from its central position, the acceleration instigates deflection of the proof mass.<sup>[2]</sup>

Plates that are fixed to the substrate and these fingers are placed in between. A single finger and pair of fixed plates make up a differential capacitor, and the deflection of the proof mass is determined by measuring the differential capacitance. For the various elements used need to know all the mechanical behaviour for better understanding, microscopic mechanical system design is even simpler. Rules are still maintained from the mechanical dynamics as basic and familiarized in this small world, a non-well mechanically characterized material is used as a basic structure. Poly silicon material used to make mechanical structures in most of the MEMS systems. It's the most prompt and more compatible material for manufacturing the IC in the IC world. To fully understand poly silicon's mechanical properties a little work has been done. In the world of microscopic, the material properties may change, for the same poly silicon is the best example. Poly silicon is too brittle and fragile, it's used rarely in this micro world, as a part of mechanical element, it has the capacity to withstand all deflection, and even very small deflection can be observed. It turns out to an ideal material at maximum level. MEMS sensors are the combination of mechanical component and electrical component. MEMS sensors are otherwise called as micro machines, used for sensing the Mechanical-electro devices. In Mechanical devices MEMS sensors represents a continuum bridging in mechanical sensors at the other in the mems spectrum and electronic sensors at one end. A MEMS sensor is not only restricted to an electrical functionality but also it gives access to the mechanical functionality for example the element have the capability for deflect, spin vibrate, rotate and spin.<sup>[2]</sup>

MEMS technology developed, integrates and extends from the roots of micro-electronics industry. For integrated circuit(IC) and processing the manufacturing of MEMS, specifically processed. To produce small mechanical structures and components, a conventional special techniques to be developed, in a micrometre scale for calibrating. As shown in Fig.1 the IC fabrication made using a Silicon (Si) wafer, in the majority of MEMS sensors onto a Si base are thin layers of materials are deposited. 3D structures such as spring, gears beams, diaphragms are then selectively etched away to leave microscopic. This way is other ways known as bulk micromachining. Lot of techniques was developed for etching and micromachining concepts<sup>[2]</sup>.

Kulite Semiconductor, in the mid-1960s was the first micro machined diffused or pressure sensors, as they were originally made. In other hand known as a silicon cell, piezo resistive pressure sensor. A pressure sensor with piezo resistive strain gauges diffused into it consists of a micro machined silicon diaphragm and fused to a silicon or glass back plate. Through a port to the environment the top-side of the diaphragm is exposed and to a pressure differential deforms in reaction in to it.<sup>[2]</sup> The digitalized electrical signal which is seen in the output module of a sensor is then extent to the diaphragm deformation is then manipulated and converted to a module.



**Figure 1: Silicon Wafer Sensor**

#### **Before commercialisation Disadvantages of MEMs**

- To house the two-chip structure a larger packages are generally required.
- Silicon area is larger normally.
- The multi-chip modules are lower in yield and required extra assembly steps.
- A larger sensor structure required for stray fields.
- In chip to chip interconnections amplitude signals are high from the sensor side.

#### **Applications of MEMs Sensors**

- Ink jet printers which uses thermal bubble ejection to deposit ink on paper or piezo electric materials.
- Used in accelerometers in modern cars, choppers, drones.
- Used in electronic devices such as digital cameras, cell phones.
- The Gyroscopic MEMS sensors will be used for sensing the object.
- The STM microscopes(scanning tunnelling microscope) will have mems sensors, to sense the micro level objects.
- MEMS technology will be used in the field of bio technology for DNA applications, electroporation, and capillary electrophoresis.
- Disposable sensors used to monitor blood pressure in ICU's andalso as respiratory elements for calculating respiratory level of a human being.

#### **FABRICATION PROCESS OF MEMS TECHNOLOGY**

MEMS Fabrication is done by most sophisticated processes such as:

- Chemical deposition
- Lithography
- Electron beam lithography (EBM)
- Deposition process
- Physical deposition

- Patterning

Semiconductor device fabrication with a process for creating integrated circuits used in daily electrical and electronic circuits. It is sequence of photo lithographic and chemical processing. The plant where the semiconductor fabrication is done called as “FAB”.

## DEPOSITIONS & PROCESS

Deposition occurs when molecules settle out of a solution (e.g.: silica substrate deposition on a semiconductor wafer)

- Atomic layer deposition
- Chemical vapour deposition (CVD)

### Chemical Vapour Deposition

It's a chemical process in which high quality, high performance, solid materials are produced. In semiconductor industry it is used to produce thin films.

Micro fabrication process widely used CVD to deposit material in various forms including micro crystalline poly crystalline, amorphous and epitaxial.

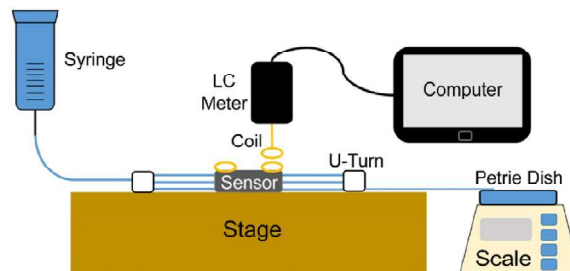
## METHODOLOGY

### SENSITIVE, DIFFERENTIAL MEMS CAPACITOR FOR MONITORING THE MILLILITRE DYNAMICS OF FLUIDS IN MEDICAL FIELD

A device, with MEMS sensors has been fabricated and tested for calibrating low fluid pressures and slow flow rates. The motivation and main theme of mems technology in medical field, was to measure clinically relevance ranges of slow-moving fluids in living systems, such as the cerebrospinal fluid in the brain. For potential clinical utility, the device can be read transcutaneous, by inductive coupling to MEMS capacitive sensors in circuits, with resonant frequencies in the MHz (megahertz) range <sup>[3]</sup>. The flow rates for signal shifts ranging from 0–42 mL/h and differential pressure levels between 0.1 and 2 kPa <sup>[4]</sup> have been measured. The sensors are fabricated utilizing state-of-the-art MEMS technology. The main feature of the chips is circular flexible membranes with a diameter,  $d = 500\mu\text{m}$  this geometry reduces stress on the edges of the membrane while maximizing and changing the sensitivity of the device <sup>[5]</sup>. Both pressure and flow rate sensing MEMS devices have been successfully designed and tested to demonstrate that it is possible to monitor both parameters in a hydrocephalic patient or other slow moving fluid. The heart flow rate sensor and control unit of mems sensor is shown in figure 2 & 3<sup>[6]</sup>. This type of sensors are also used in the treatment of persons on ECMO machine.



**Figure.2: Heart Flow Rate sensor**



**Figure.3: MEMS Sensor used in Cerebrospinal Fluid Dynamics Machines Control Unit**

## **THRUSTERS ARRAYS IN SPACE THROUGH APPLICATION OF MEMS SOLID PROPELLANT LAUNCH AND ON-ORBIT ENVIRONMENT TESTS**

Lack of reliability and flight heritage in space environments is one of the most important barriers encountered and faced to the space application of MEMS technology. For the Validation and verification test of MEMS technology, in this review the solid propellant thrusters array of MEMS was selected. At the qualification level before launch, flight demonstration in orbit and environment test MEMS thrusters' module were performed successfully. Random vibration loads and sine burst were applied to the module of MEMS thrusters is applied in case of launch test.<sup>[7]</sup> The on orbit environment test were carried out for the thermal vacuum tests. The characteristics were less than 0.7% for the on-orbit environment test and launch vibration test. Suddenly after the vibration tests, all the operational requirements were successfully verified. The thruster's module showed stable normal function, before the ignition and the tests successfully verified the manufacturing process.

The fabrication process of MEMS thrusters was divided into three steps: the fabrication of the micro-nozzle, intermediary, and seal layer; the fabrication of the micro-igniters; and the final assembly process, including the loading of the propellant. In the first step, the micro-nozzle layer, intermediary layer, and seal layer were fabricated by anisotropic etching of photosensitive glass. Next, the micro-igniters comprising a heater, a membrane, and a propellant chamber was fabricated. Platinum (Pt) was adopted as the material of the heater because it will possess high stability at high temperatures and is resistant to oxidation and corrosion properties. A 40  $\mu\text{m}$  thick glass membrane was selected from the viewpoint of structural stability. Glass membranes have physical properties such as lower thermal conductivity and lower fabrication costs than conventional dielectric membranes. The micro-igniters were fabricated by Pt/Ti deposition and patterning, chemical-mechanical polishing (CMP), anisotropic wet etching, and UV bonding process<sup>[8]</sup>.

In this study, to achieve a reliable electrical contact between the MEMS thrusters and its control board in launch

vibration and thermal vacuum environments, an electrode pad designed along with spring-loaded pins instead of the conventional soldering electric wire is proposed. The temperature was maintained constant for 1h. Then, it was heated again to 585°C with a ramp rate of one degree Celsius per minute and maintained at this temperature for 1 hour. Finally, the glass was cooled at a cooling rate of  $-3^{\circ}\text{C}/\text{min}$ . During this heat treatment, the properties of the UV-exposed glass vary significantly because of re-crystallization. Then after the heat treatment, the wafer was soaked in a diluted 10% hydrofluoric (HF) acid solution. The general etching ratio of glass-ceramic to vitreous glass is 19:1. Because the unexposed area was partially etched, the surface of the wafer was roughened. Subsequently, in order to make its surface flat the wafer was chemically and mechanically polished the membrane layer was fabricated by patterning the heater and electrodes onto the glass wafer. First, a photoresist was spin-coated, onto the glass and patterned by photolithography to form the heater and electrodes. To achieve reliable electrical contact and survivability, we proposed electrode pads design combined with spring-loaded pogo-pins. The electrical interface on the thrusters was directly connected to the pogo-pins on the thrusters control board and fixed by a plastic cover made of Delrin® with space heritage<sup>[9]</sup>. The function of the thrusters' module was tested, by the external command to the thrusters control board. The ignition test performed under ambient conditions at the MEMS thrusters. For example, dummy thrusters without solid propellant will be used to prevent ignition during a full function test of the system level thermal vacuum test. The mems sensors used in the space, will test the following things:

- launch vibration
- on orbit environmental sensing

Another feature that the ISRO (Indian Space Research Organisation) used in the rocket propulsion systems of Polar Satellite Launch Vehicles (PSLV) is MEMS acoustic sensors which are piezo electric type. The sensors can be used for any type testing hard test, like humidity test, vibration test, soak test and temperature soak test, the MEMS acoustic sensors has the capability of withstanding any kind of test mentioned above<sup>[10]</sup>. The MEMS sensor are used in flights and tested, it is the first profoundly developed and in the history of 12 successive PSLV flights. The process and fabrication of MEMS Acoustic Sensors was done by ISRO at CEERI, PILANI.

The main objective of space department is to undertake aid, promote, guide & coordinate the R&D in the field of Micro-Electro-Mechanical Systems (MEMS) semiconductor technology and process technologies relating to semiconductor processing in the existing 6" wafer fab.



**Figure.4: MEMS Acoustic Sensor**

### **Specifications MEMS Acoustic Sensors**

On Silicon bulk layer micro machined with piezoelectric sense layer and silicon diaphragm.

Minimum range of the acoustic sensor is about 100dB and maximum range of 180dB. The Octave centre frequency ranges from 31.5 Hz to a range of 6.5 KHz in  $1/3^{\text{rd}}$ , whereas sensitivity of 200uV/Pa from 150uV/Pa, with a linearity amplitude of  $\pm 2\text{dB}$ .

Frequency response of the MEMS acoustic sensors is about  $\pm 3\text{dB}$ , with a weight of 130 grams and an operating temperature range from  $-45^{\circ}\text{C}$  to  $+130^{\circ}\text{C}$ .

### **LOW-COST MEMS SENSORS 3D INDOOR POSITIONING SYSTEM AND CELLULAR PHONES ACCELEROMETERS USED IN CAMERAS**

Positioning system is necessary for implementing in indoor for directional guidance and localization, in the absence of GPS, inertial Measuring Units (IMUs) can be used to detect the movement of a pedestrian. A 3D indoor MEMS sensors- locating system using foot mounted low cost is to locate the altitude and location of a person in 3D view, and to plot the path travelled by the person; the sensors including gyroscopes, accelerometers and a barometer. To estimate the pedestrian's motion information, PDR (Pedestrian Dead-Reckoning), is developed. This system is used for collection of information like accelerometers and gyroscopes, which are used to estimate the pedestrian's rough position. To identify the standing still momenta zero velocity update (ZUPT) algorithm is developed <sup>[11]</sup>.

To get correct exact height information result, following instructions to be followed, the readings collected by the barometer are integrated then coupled with the dates got from accelerometer and then the change in altitude. The tracking locations at outdoors GPS (Global Positioning System) is used prominently. The GPS cannot be used in indoor environments because of sever signal attenuation. Précised indoor positioning systems are in high demand because it used for locating. Some of the other applications used for tracking kids locations in supermarkets, Malls. This system used also for elderly peoples in providing supports and to find a car in a parking area <sup>[12]</sup>.

Previously the cameras are of bigger size but the present ongoing technologies of cameras is embedded in the android mobiles in the smaller range and higher pixel lengths this is mainly due to presence of gyroscopic and accelerometer sensors. The integrated approach presented further challenges. Many standard production steps that improve the mechanical structure degrade the electronics and vice versa. The normal technique annealing is used for flattening out the Polysilicon mechanical structure (For controlling the structure from high temperatures). While for the mechanical structures the annealing process is suitable and it can degrade or destroy the Biomes transistors used in the signal conditioning electronics. So compatible mechanical and electronic process methods had to be devised.

Due to unavailability of the standard software's, it's been a challenge for the designer to accomplish tasks easily. Modern integrated circuits are rarely designed by hand. Complex CAD and simulation software is used to help design and optimise the designer's concepts.

For the customer needs, in most of the CAD software and simulation software MEMS design is still in its infancy and develop all part of their CAD and simulation software to suit their customer needs by most of the MEMS manufacturers <sup>[13]</sup>.

Design challenge is perhaps the greatest one in the fabrication process Techniques for building three-dimensional

MEMS structures had to be designed and devised. For cut out structures from solid, Polysilicon Trench can be used. To move freely, etching can be used but additional process steps to be used to remove the material from the Polysilicon.

### **MEMS-BASED ACCELEROMETERS AND CURRENT SENSORS IN MACHINERY FAULT DIAGNOSIS**

In machinery fault diagnosis due to their low power consumption recently the MEMS based sensors have shown higher attraction. Low cost, small size, mobility, and flexibility.

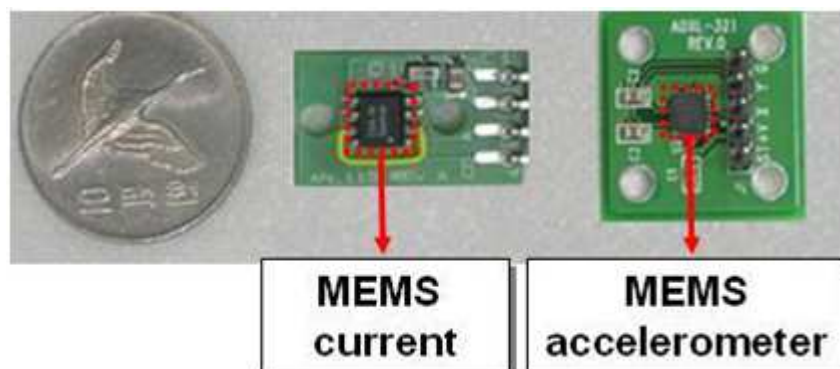
MEMS-based sensors as shown in FIG.6 are strong enough for using instead commercial accelerometers and current sensors that are used for fault diagnosis. For offering at least 38% performance improvement in classification accuracy specifically, the MEMS-based accelerometers are more used, much effective in protecting the intrinsic information of various induction motor failures than a MEMS-based current sensors are used.

In recent years, micro MEMS technology is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro fabrication technology.

Even though MEMS-based accelerometers and current sensors can be applied to machinery fault diagnosis systems, their usage in real fault diagnosis technology applications is still limited because their availability for machinery fault diagnosis is not completely proved yet. This fault diagnosis scheme first calculates statistical values in both vibration and current signals recorded by MEMS-based sensors. MEMS-based accelerometer contains a polysilicon surface micromachined sensor and signal conditioning circuitry, to implement open-loop acceleration measurement architecture<sup>[14]</sup>. This accelerometer gives the outputs as analog voltages, that are proportional to acceleration by sensing changes. The sensor converts the capacitance changes due to acceleration into a voltage.



**Figure.5: Accelerometer**



**Figure.6: MEMS Accelerometer**



## CONCLUSIONS

The wide use of sensors in the every domain is becoming the great demand for the technologists and researchers to implement new ideas and technologies in the concept of micro electrical and mechanical systems. By this study on MEMS we conclude that the use of MEMS in the field of engineering, space, medical etc., will have a huge impact on the scientific world and leads to research and development of many integrated devices. The global trend of manufactures is moving towards the fabrication of MEMS sensors with the help of special equipment's. Differential MEMS capacitors, it can measure flow in the rate of millimetre where it converges to a different subject of "MEMS FLUID DYANMICS".

In case of aerospace domains space thrusters' where mems solid propellant, will be used to test the launching, orbit and environment by the mems sensors is a great reflected technology in the aerospace, still the research is going at the NASA,ISRO to effectively use of MEMS SENSORS to sense about the conditions and factors on the space atmosphere.

The technology in the field of electronic devices such as mobile phones has been rapidly increasing day by day with new features .The use of gyroscopic mems sensors and accelerometers in the cellular phones, for navigation purposes etc., and RF (RADIO FREQUENCY) devices where it senses the desired signal to the respective devices is ease now, because of SENSORS. This is how the technology in the field of MEMS has been rapidly increasing, in every domain however, we have shown here some of the demanding technologies in the field of medical, space, engineering, cellular devices.

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